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EVALUATION OF THE MARISAT SATELLITE UHF WIDEBAND CHANNEL (U)

by

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ABSTRACT

The use of the MARISAT satellite UHF wideband channel as a radio link for multiple users is investigated. An analytical evaluation of the link is performed for up to 10 users sharing the non-processing transponder's 500 kHz bandwidth. The terminal link carrier-power-to-noise-power-spectral-density ratio, C/N_o, is evaluated for data rates of 2.4, 4.8 and 16 kbps, and for terminal effective isotropic radiated power (EIRP) levels from 17 to 30 dBW. Analyses are performed for cases in which all terminals transmit with the same EIRP and also for cases in which a single user is either 3 dB above or below the other users. A variety of loading schemes are considered to demonstrate the variation in user SNR degradation due to hardlimiting on-board the transponder. The terminal C/N_o is compared to the minimum performance requirement plus a 3 dB margin to determine the link capacity.

Two experiments which were run to evaluate the MARISAT UHF wideband channel spectrum usage and to measure the terminal C/N_o are described. Power spectral density graphs of the wideband channel and individual subchannels are presented. The results of a 24-hour test to monitor the terminal C/N_o are discussed in terms of the observed C/N_o fluctuations and spectrum anomalies.

RÉSUMÉ

Ce rapport examine l'utilisation d'une voie UHF à large bande du satellite MARISAT comme liaison radio pour plusieurs utilisateurs. Une évaluation analytique de cette liaison est accomplie pour un nombre d'utilisateurs, plus petit ou égal à 10, partageant la bande de 500 Khz du répondeur sans traitement. Le rapport porteuse - densité spectrale de bruit, C/N_o, est évalué pour des taux de transmission de 2.4, 4.8 et 16 Kbps, et pour des niveaux de puissance isotrope rayonnée équivalente (EIRP) de 17 à 30 dBW. Des analyses sont effectuées pour des cas dans lesquels tous les terminaux transmettent avec le même EIRP et aussi pour des cas où un simple utilisateur a 3 dB de plus ou moins que les autres. Une combinaison de différentes charges est considérée en vue de démontrer la variation de la dégradation du SNR due aux limites strictes du répondeur à bord du satellite. Le C/N_o du terminal est comparé aux demandes de performance minimum, plus une marge de 3 dB, pour déterminer la capacité de la liaison.

Ce rapport décrit deux expériences menées pour évaluer l'utilisation du spectre UHF de la voie à large bande de MARISAT et pour mesurer le C/N_o du terminal. Des graphiques de la densité spectrale de puissance de la voie à large bande et des sous-canaux individuels sont présentés. Les résultats d'un test de 24 heures pour surveiller le C/N_o du terminal sont discutés en termes du C/N_o observé et des anomalies du spectre.

EXECUTIVE SUMMARY

The Department of National Defence (DND) is making increasing use of satellite communications (SATCOM) to relay voice and data between land, sea and air resources. SATCOM is being used by DND for both domestic and NATO exercises. DND is currently considering leasing UHF transponder time on the MARISAT F-1 satellite. In this report the feasibility of using the MARISAT UHF transponder for the transmission of digital voice at rates of 2.4, 4.8 and 16 kbps is investigated.

The MARISAT satellite has three independent transponding UHF repeaters. There are two 25 kHz channels and one 500 kHz channel, each of which is a fully redundant repeater. It is the wideband (500 kHz) channel that is of particular interest in this report. The channel is divided into twenty subchannels each having a 25 kHz bandwidth. The data rates typically used within the subchannels vary from 75 to 2400 bps, although higher rates are possible.

The link analysis, which is based on deriving the terminal carrier-power-to-noise-power-spectral-density ratio (C/N_o), shows that only 2 or 3 users at most can be supported at a data rate of 16 kbps, assuming a 3 dB link margin. For the majority of the loading cases considered, at least 10 users could be supported at the 2.4 and 4.8 kbps data rates, again with a 3 dB link margin.

The results of a limited 24-hour terminal C/N_o test using the MARISAT transponder and terminal test equipment demonstrate the terminal C/N_o fluctuations when the transponder is only lightly loaded. An investigation of the spectrum usage during this test period shows two subchannels to be occupied by unauthorized users/sources.

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1. INTRODUCTION

The Department of National Defence (DND) is making increasing use of satellite communications (SATCOM) to relay voice and data between land, sea and air resources. SATCOM is being used by DND for both domestic and NATO exercises. One band that has seen considerable operational use over the past two decades is the UHF band. This band is typically used by high mobility terminals having relatively broad beam antennas. DND is currently considering leasing UHF transponder time on the MARISAT satellite.

The MARISAT satellite has three independent transponding UHF repeaters. There are two 25 kHz channels and one 500 kHz channel, each of which is a fully redundant repeater. It is the wideband (500 kHz) channel which is of particular interest in this report. The channel is divided into twenty subchannels each having a 25 kHz bandwidth. The data rates typically used within the subchannels vary from 75 to 2400 bps, although higher rates are possible.

The aim of this report is to analyze the potential of the MARISAT UHF wideband channel for the transmission of digital voice at rates of 2.4, 4.8 and 16 kbps. Sections 2 and 3 provide an analysis of the link and estimates of the capacity under a number of different transponder loading cases. This analysis closely follows the methods given in [1]. The results of a 24-hour carrier-power-to-noise-power-spectral-density ratio (C/N_o) experiment using the MARISAT transponder is discussed in Section 4. A preliminary investigation into the transponder spectrum usage is also discussed in Section 4. Concluding remarks concerning the analysis and experimental work are given in Section 5.

2. LINK CHARACTERISTICS

2.1 TRANSPONDER CHARACTERISTICS

The uplink frequency band for the MARISAT wideband channel is from 302.45 to 302.925 MHz, with 25 kHz subchannel spacing as given in Table 2.1 [2,p.51-3]. The uplink signal is filtered, hard-limited, frequency translated to the range 248.85 to 249.325 MHz for the downlink, and then amplified to provide 56 W (17.5 dBW) of rf power. The transponder characteristics are given in Table 2.2.

The closest MARISAT transponder to DREO is located in synchronous orbit at approximately 106.5° W longitude. Although the satellite is in an inclined orbit (about 8°), the transmit and receive antenna gains as seen by a geographically fixed user are each expected to vary by no more than 1 dB over a 24-hour period.

The inclined orbit is also expected to cause a minimal variation in the path loss, an additional one-way loss of no more than 1 dB. The average path loss assumed for the MARISAT transponder is given in Table 2.3, which is obtained from measurements of LES-9 [1,p.3]. It will be shown in the analysis that while the value of the path loss is important, it is

not the critical element in determining link capacity. Any difference in the uplink receive signal level can be compensated for by an appropriate change in the terminal EIRP. Differences with the downlink path loss will be shown to be even less significant than for the uplink. Briefly, the reason is that the terminal receiver noise power spectral density (PSD) is typically overwhelmed by the noise transmitted by the satellite (satellite receiver noise PSD and intermodulation noise). Hence, changes in the downlink path loss affect both the signal and noise terms by the same degree.

Channel	Downlink (MHz)	Uplink (MHz)
1	248.850	302.450
2	248.875	302.475
3	248.900	302.500
4	248.925	302.525
5	248.950	302.550
6	248.975	302.575
7	249.000	302.600
8	249.025	302.625
9	249.050	302.650
10	249.075	302.675
11	249.100	302.700
12	249.125	302.725
13	249.150	302.750
14	249.175	302.775
15	249.200	302.800
16	249.225	302.825
17	249.250	302.850
18	249.275	302.875
19	249.300	302.900
20	249.325	302.925

Table 2.1. Subchannel number and center frequency.

MARISAT Satellite UHF Wideband Channel	
Uplink Center Frequency	302.6875 MHz
Downlink Center Frequency	249.0875 MHz
Bandwidth	500 kHz
Receive G/T	-18 dB/K
UHF Antenna Coverage	19° (earth coverage)
EIRP	28 dBW

Table 2.2. MARISAT satellite UHF wideband channel characteristics.

Uplink Path Loss	173.9 dB
Downlink Path Loss	172.4 dB

Table 2.3. Average path loss assumed for MARISAT satellite UHF uplink and downlink.

2.2 TERMINAL CHARACTERISTICS

The ground terminal considered for the link analysis uses an AN/WSC-3 UHF transceiver, and a tripod-mounted crossed-yagi antenna. Although the WSC-3 only provides a half-duplex communications capability, two WSC-3 units can be combined to support full duplex communications over the transponder. Typical characteristics for the WSC-3 terminal are given in Table 2.4 [2, p.62].

Transmit power (max)	20 dBW
Transmit antenna gain (typical)	10 dBi
EIRP (max)	30 dBW
Receive antenna gain (typical)	10 dBi
System noise PSD	-200 dBW

Table 2.4. WSC-3 UHF ground terminal characteristics.

3. LINK CALCULATIONS

3.1 LINK ANALYSIS

The purpose of this section is to investigate the communications capacity as a function of the number of users and terminal EIRP, given the terminal and transponder characteristics detailed in Section 2. The figure of merit to be computed in the analysis is the C/N_o. The derivation of this value is significant in that it can be easily compared to the required terminal C/N_o, which for BPSK modulation is given in Table 3.1 [1]. To allow for variations in the path loss, satellite antenna gain, and transponder loading, a C/N_o margin of 3 dB should be included in the link design.

The derivation of the C/N_o is fairly straightforward. The user SNR at the input of the transponder is first determined. The SNR suppression factor is then calculated. This leads directly to the user output SNR at the transponder. The terminal C/N_o is then obtained by calculating that portion of the downlink signal destined for the i'th user and comparing it with the sum of the receiver system noise and the received downlink noise.

Data rate (kHz)	Required C/N_o (dB·Hz)
2.4	43.0
4.8	46.0
16.0	51.2

Table 3.1. Required terminal C/N_o.

The transponder receive signal, S_i, for the i'th user is easily determined given the ground terminal EIRP ($EIRP_G$), uplink path loss (L_u), and transponder receive antenna gain (G_t),

$$S_i(i) = EIRP_G - L_u + G_t \quad [dBW] \tag{3-1}$$

The transponder noise power is given by the product of the transponder noise PSD and channel bandwidth of 500 kHz. Given a transponder G/T value of -18 dB/K and an antenna gain of 10.5 dB, the transponder noise temperature is 708 K. The transponder noise PSD is therefore -200.1 dBW/Hz and the transponder noise power is N_i=-143.1 dBW. For the i'th user the transponder input SNR when measured over the 500 kHz channel, $SNR_i(i)$, is given by

$$SNR_i(i) = S_i(i) - N_i \quad [dB] \tag{3-2}$$

The uplink signals and receiver thermal noise are filtered, translated to a low IF, filtered, amplified to an intermediate level, upconverted to the transmit frequency and then amplified to to 56 watts. The hard-limiting introduces an SNR degradation for each user. The ratio of the output to input SNR for the i'th user is given by the SNR suppression factor, $\alpha(i)$, which is defined in [1,p.9]

$$\alpha(i) = SNR_o(i) - SNR_i(i) \quad [dB] \tag{3-3}$$

where SNR_o is the transponder output SNR. The SNR suppression factor is calculated using the time-domain techniques described in Appendix C of [1]. In summary, $\alpha(i)$ is a nonlinear function of the user input SNR, the limiter wideband output magnitude and other users' signal envelope. Appendix A of this report tables the SNR suppression factors for the loading cases considered in the next section.

The total transponder transmit power received at the ground terminal (P_r) is obtained from the transponder EIRP ($EIRP_t$), the downlink path loss (L_d), and the ground terminal receive antenna gain (G_g),

$$P_r = EIRP_t - L_d + G_g \quad [dBW] \tag{3-4}$$

Noting that the transponder output signal received at the ground terminal is comprised of the received noise power, N_r, plus the sum of individual user signals, one obtains

$$S_r(i) = P_r \frac{S_r(i)}{N_r + \sum_j S_r(j)} = P_r \frac{S_r(i)/N_r}{1 + \sum_j S_r(j)/N_r}$$

Taking the logarithm of $S_r(i)$ and defining the linear (transponder output) signal-to-noise ratio for the i'th user as $SNR_o(i) = S_r(i)/N_r$,

$$P_r(i) = P_r + SNR_o(i) - 10\log[1 + \sum_{j=1}^{L} SNR_o(j)] \quad [dBW] \tag{3-5}$$

The terminal received noise power for the i'th user is therefore described by

$$N_r(i) = P_r - 10\log[1 + \sum_{j=1}^{L} SNR_o(j)] = P_r(i) - SNR_o(i) \quad [dBW] \tag{3-6}$$

The effective noise PSD, N_o, for the ground terminal is the sum of the receiver system noise PSD, N_s, and the received noise power normalized by the channel bandwidth, B_c,

$$N_o = N_s + (N_r(i) - 10\log B_c) \quad [dBW/Hz] \tag{3-7}$$

Finally, the desired figure, C/N_o, is obtained using

$$C/N_o = P_r(i) - N_o \quad [dB\cdot Hz] \tag{3-8}$$

3.2 C/N_o CALCULATIONS

The terminal C/N_o values are calculated for a few different loading scenarios. A list of the transponder loading examples considered in this report is given in Table 3.2.

The first loading case in Table 3.2 is chosen to demonstrate the change in capacity of the system in terms of the terminal C/N_o when all users transmit with an EIRP of 20 dBW. The terminal C/N_o is examined for 2 to 10 users. An identical analysis is also performed for two other terminal EIRP levels, cases (ii) and (iii). This is done to illustrate the diminishing returns in terminal C/N_o when all users increase their EIRP by a similar amount. The remaining cases demonstrate the effect on terminal C/N_o when one user is either 3 dB above or below the EIRP level of the other L-1 users.

Loading Case	Terminal EIRP (dBW) L-1 Users	Terminal EIRP (dBW) 1 User	Range of Users, L
(i)	20	20	2-10
(ii)	25	25	2-10
(iii)	30	30	2-10
(iv)	20	17	2-10
(v)	20	23	2-10
(vi)	22	25	2-10
(vii)	25	22	2-10

Table 3.2. Transponder loading cases.

An example of a link calculation which follows the analysis given in the previous section is given below for case (v) of Table 3.2 with L=5 users. For convenience define the 4 users at an EIRP of 20 dBW as Type I users and the single user at an EIRP of 23 dBW as a Type II user. Where appropriate, the equation numbers from the previous section are included alongside the calculation.

Terminal EIRP		
Type I user		20 dBW
Type II user		23 dBW
Uplink path loss		173.9 dB
Satellite Receive Antenna Gain		10.5 dBi
Transponder Received Signal Power	(3-1)	
Type I user		-143.4 dBW
Type II user		-140.4 dBW
Transponder system noise PSD		-200.1 dBW/Hz
Transponder bandwidth		500 kHz
System Noise Power		-143.1 dBW

Transponder input SNR	(3-2)	
Type I user		-0.3 dB
Type II user		2.7 dB

SNR suppression factor		
Type I user		-4.12 dB
Type II user		-3.69 dB
Transponder output SNR	(3-3)	
Type I user		-4.4 dB
Type II user		-1.0 dB
Transponder EIRP		28.0 dBW
Downlink path loss		172.4 dB
Terminal receive antenna gain		10.0 dBi
Terminal total received power	(3-4)	-134.4 dBW
Signal power/user	(3-5)	
Type I user		-143.9 dBW
Type II user		-140.5 dBW
Terminal received noise power	(3-6)	-139.5 dBW
Terminal receiver system noise PSD		-200.0 dBW/Hz
Effective receiver noise PSD	(3-7)	-194.9 dBW/Hz
C/N_o	(3-8)	
Type I user		51.0 dB·Hz
Type II user		54.4 dB·Hz

An important observation to be made from the above example is in the comparison between the terminal receiver system noise PSD and the effective receiver noise PSD. The level of the received noise power causes the effective receiver noise PSD to be more than 5 dB greater than the terminal receiver system noise PSD. Consequently, if the terminal receive signal varies by as much as 2 or 3 dB due to changes in the path loss or antenna gain, there is a minimal impact on terminal C/N_o since both the signal and dominant noise term are attenuated by the same amount. It should also be noted in the above example that the lower EIRP users experience an SNR suppression factor which is 0.5 dB lower than the higher EIRP user.

Tables of the available C/N_o per user for the loading cases listed in Table 3.2 are given in Appendix B. Graphical representations of the available user C/N_o for these cases are given

in Fig. 3.1-5 as a function of the number of users. Included in these figures are *C/N_o thresholds* (the solid horizontal lines) corresponding to a 3 dB link margin over the minimum required C/N_o given in Table 3.1 for the three data rates.

Fig. 3.1 illustrates the available terminal C/N_o when all users transmit with the same EIRP. Three different EIRP levels are considered: 20, 25 and 30 dBW. It should be noted that with a terminal EIRP of 20 dBW, only a single user at a data rate of 16 kbps can be supported (with a link margin of 3 dB) while more than 10 users can be supported for both the 2.4 kbps and 4.8 kbps data rates. Based on the rate of decrease in C/N_o at L=10, it is expected that at least 11 users could be supported at the 4.8 kbps data rate and possibly the maximum of 20 users at the 2.4 kbps data rate. Fig. 3.1 also shows that when the terminals increase their EIRP by 5 dB, the increase in available C/N_o per user for L=2 is only 2.2 dB and just 0.8 dB for 10 users. Increasing the terminal EIRP an additional 5 dB to 30 dBW produces further increases in the available terminal C/N_o of only 1.4 dB for L=2 and 0.3 dB for L=10. The primary benefit derived from increasing the terminal EIRP from 20 to 30 dBW is an increase of three users exceeding the 16 kbps data rate threshold.

The available terminal C/N_o for case (iv) of Table 3.2, in which one user transmits with an EIRP of 17 dB and the other L-1 users at 20 dBW, is shown in Fig. 3.2. For up to four users, the high and low EIRP users can be accommodated at either of the 2.4 kbps or 4.8 kbps rates; when L exceeds 4, the user at the lower EIRP should only use the 2.4 kbps data rate.

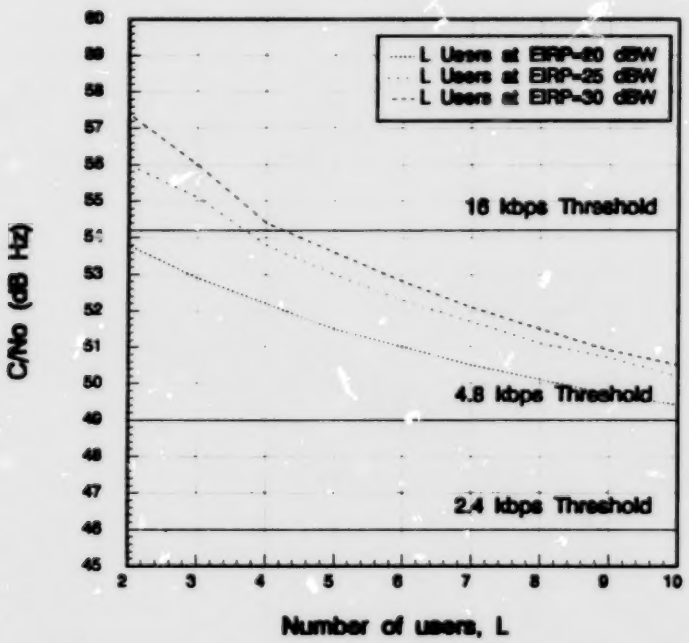

Figure 3.1 Terminal C/N_o versus number of users for terminal EIRPs of 20, 25 and 30 dBW. (Loading cases (i), (ii) and (iii).)

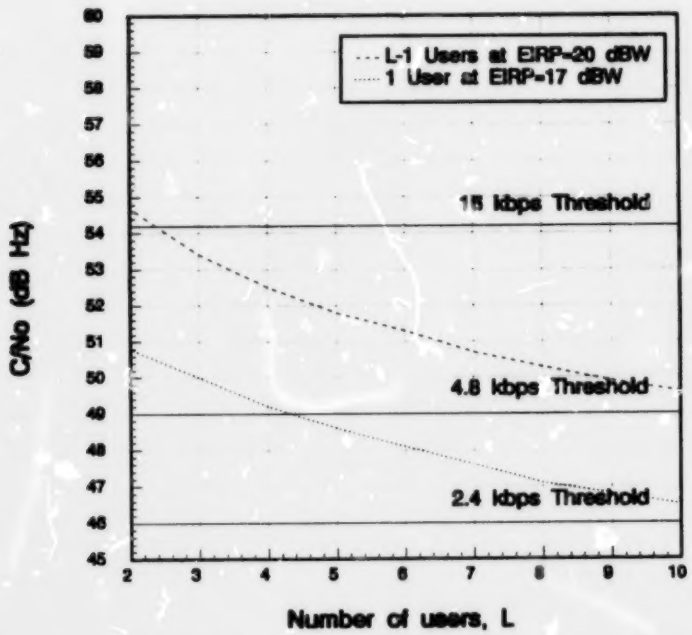

Figure 3.2 Terminal C/N_o versus number of users for L-1 users at EIRP=20 dBW and 1 user at 17 dBW. (Loading case (iv).)

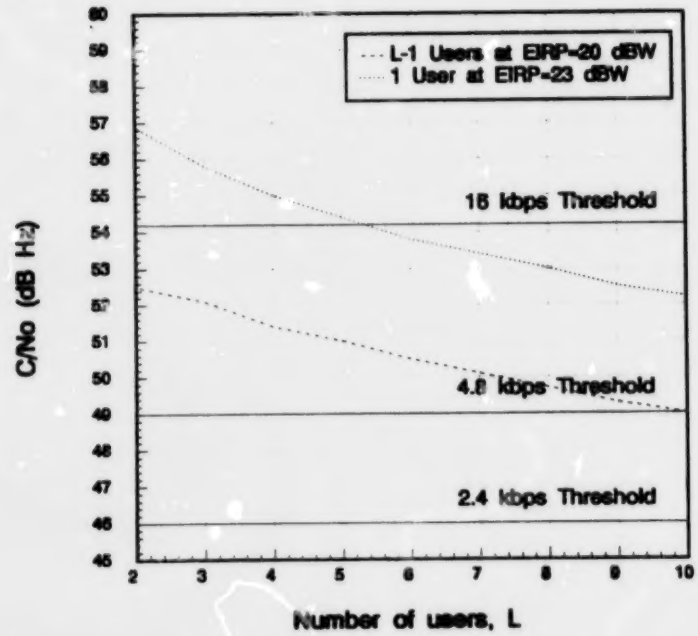

Figure 3.3 Terminal C/N_o versus number of users for L-1 users at EIRP=20 dBW and 1 user at 23 dBW. (Loading case (v).)

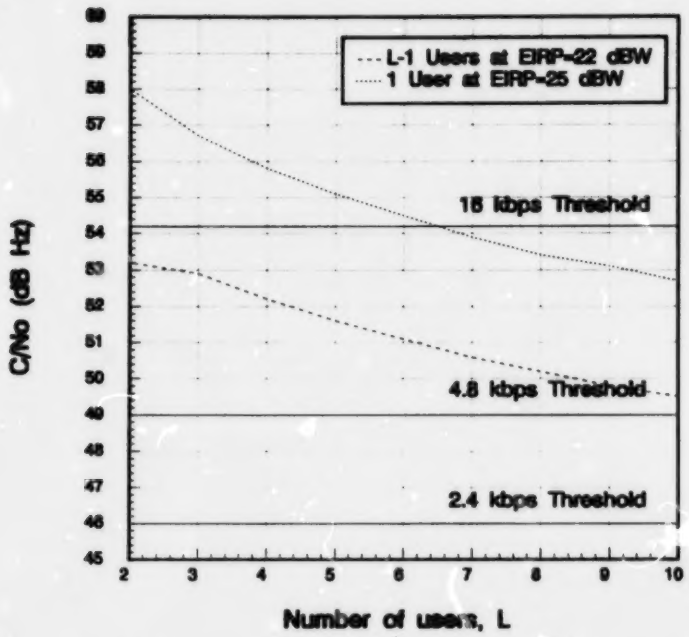

Figure 3.4 Terminal C/N_o versus number of users for L-1 users at EIRP=22 dBW and 1 user at 25 dBW. (Loading case (vi).)

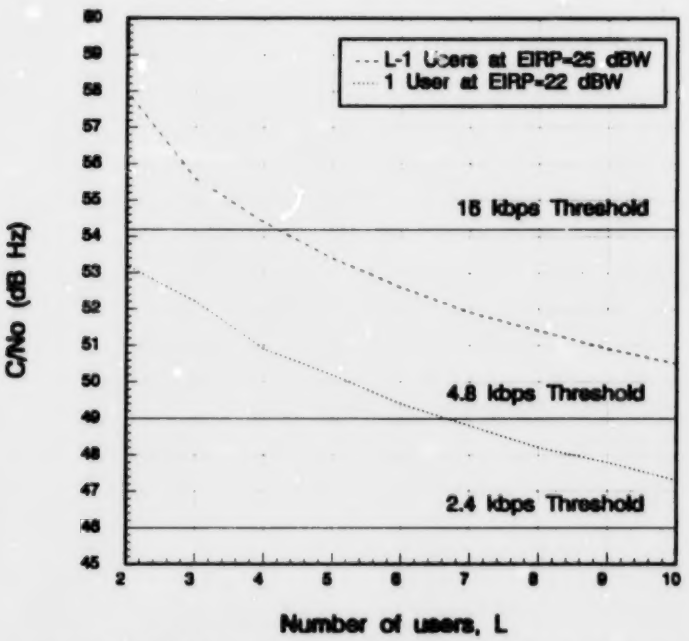

Figure 3.5 Terminal C/N_o versus number of users for L-1 users at EIRP=25 dBW and 1 user at 22 dBW. (Loading case (vii).)

Since at least 11 users under case (i) loading (L users at an EIRP of 20 dBW) could be supported at the 4.8 kbps data rate (see Fig. 3.1), at least 10 of the higher EIRP users can be supported under the case (iv) loading scheme.

Fig. 3.3 is similar to Fig. 3.2 in that L-1 users are transmitting at an EIRP of 20 dBW; however, the other user operates at an EIRP of 23 dBW. When comparing the available terminal C/N_o of the L-1 users at an EIRP of 20 dBW with that obtained with case (i) loading (where all L users transmit at the same EIRP), the former loading is observed to be degraded by 1.3 dB for L=2 and 0.4 dB per user for L=10. Consequently, there is little impact on the system when only a single user increases (or decreases) their EIRP by 3 dB. In fact, the difference in C/N_o is under 1 dB for three or more users. For this loading scheme up to 10 users may be supported at either 2.4 or 4.8 kbps. Beyond 10 users, the L-1 users can only be supported at the 2.4 kbps data rate. The high EIRP user can be supported at the 16 kbps data rate for up to L=5.

Fig. 3.4 and 3.5 are included to illustrate the available terminal C/N_o for increased terminal EIRPs with a single user either 3 dB above or below the other users. In both cases the available terminal C/N_o exceeds the 2.4 kbps and 4.8 kbps thresholds for almost all cases, the only exception being for the single user at an EIRP of 22 dBW when L exceeds 6. For loading case (vi) only the single user who transmits at an EIRP of 25 dBW can be supported at the 16 kbps data rate, as long as there are no more than five users at an EIRP of 22 dBW. For loading case (vii), as many as three users at the higher EIRP can be supported at the 16 kbps data rate.

3.3 DISCUSSION OF RESULTS

There are a number of observations to be made from the detailed link calculations provided in Section 3.2. Unless a single user transmits with a significantly greater power than the other users, there is little impact on the C/N_o performance of the other users. Although the user input SNR at the satellite will vary as the path loss and antenna gain parameters change, the SNR suppression factor also varies for each user when the transponder loading changes, and thus tends to mitigate the change in transponder output SNR. On the downlink, the antenna gain and path loss variations are even less significant since the dominant noise term in the C/N_o expression when there are more than a couple of users is the noise transmitted by the satellite, as shown in the example above. Consequently, the primary cause of terminal C/N_o fluctuations can be attributed to the changes in the transponder loading.

The calculated terminal C/N_o values for the different transponder loading schemes given above clearly indicate the capacity limitations for 16 kbps users. On the other hand, ten or more users could share the wideband channel at the 2.4 and 4.8 kbps data rates for the majority of the loading schemes.

4. EXPERIMENTAL RESULTS

A preliminary investigation of the MARISAT wideband UHF channel has been performed by DREO staff. Two sets of tests were conducted. Firstly, measurements were made of the wideband channel spectrum and usage during a period in which there were no authorized users. Secondly, a CW signal was transmitted in subchannel 11; the corresponding downlink signal was measured and monitored over a 24-hour period.

4.1 TRANSPONDER SPECTRUM AND USAGE

A plot of the typical downlink power spectral density observed over a one-week period is shown in Fig. 4.1. The spectral density given Fig. 4.1 is over the entire wideband channel. Although there were no authorized users during the time at which the measurements were made, users or at least channel anomalies are observed to be present. The largest of the anomalies occupies subchannel 3, whose downlink is centered at 248.9 MHz. (One subchannel is roughly equal to half of one horizontal division in Fig. 4.1.) From the more detailed view of subchannel 3, shown in Fig. 4.2, the anomaly appears to be a binary FSK-type modulation signal at a data rate of 2400 symbols per second. An anomaly is also observed in Fig. 4.1 in subchannel 19. A more detailed view of the power spectral density in subchannel 19 is given in Figure 4.3. The origin of this signal is difficult to assess. A band roughly 15 kHz wide is more than 5 dB above the noise floor, and two 2.4 kHz wide signals, separated by 10 kHz are almost 10 dB above the noise floor.

Unauthorized communication traffic bursts were also occasionally observed on the downlink signal. These bursts varied from a few seconds to minutes. An example of the wideband spectral density showing an intermittent user in subchannel 7 is given in Fig. 4.4. A closer examination of subchannel 7 is illustrated in Fig. 4.5. This figure indicates a narrowband modulation scheme at a rate of 1200 bps at most. The arrival and departure of other sources cause changes in the transponder loading and, as discussed in Section 3, will result in variations in the terminal C/N_o.

4.2 C/N_o MEASUREMENTS

A communications link was set up to measure the carrier power and effective receiver noise spectral density using subchannel 11 of the MARISAT UHF wideband channel. The experimental set up is shown in Fig. 4.6. A CW signal source and UHF amplifier were used to generate a stable, high power UHF signal. The terminal receive signal was amplified and then split into two paths. One of the power splitter outputs was fed to a spectrum analyzer for computer automated measurements of the carrier power and noise PSD. The other output of the power splitter was fed to a different spectrum analyzer where the envelope of the CW signal was taken and then fed to a strip chart recorder.

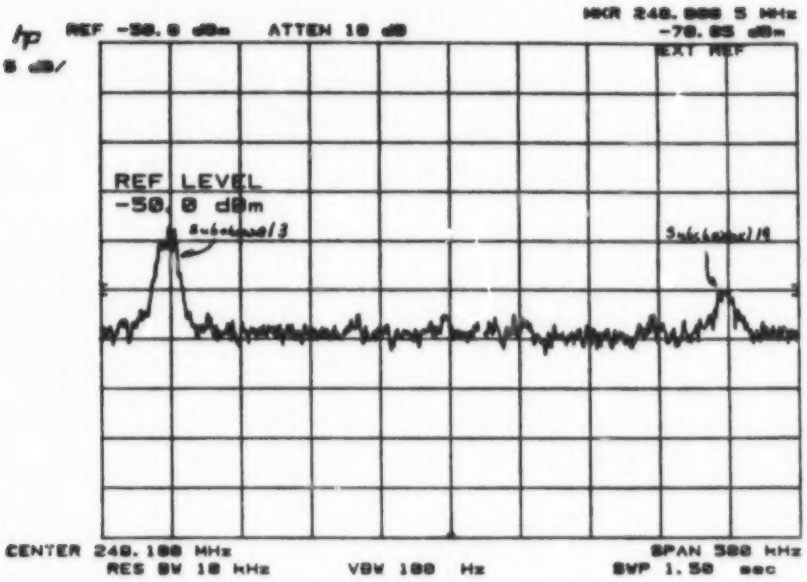

Fig. 4.1. Spectral density of the MARISAT UHF wideband channel.

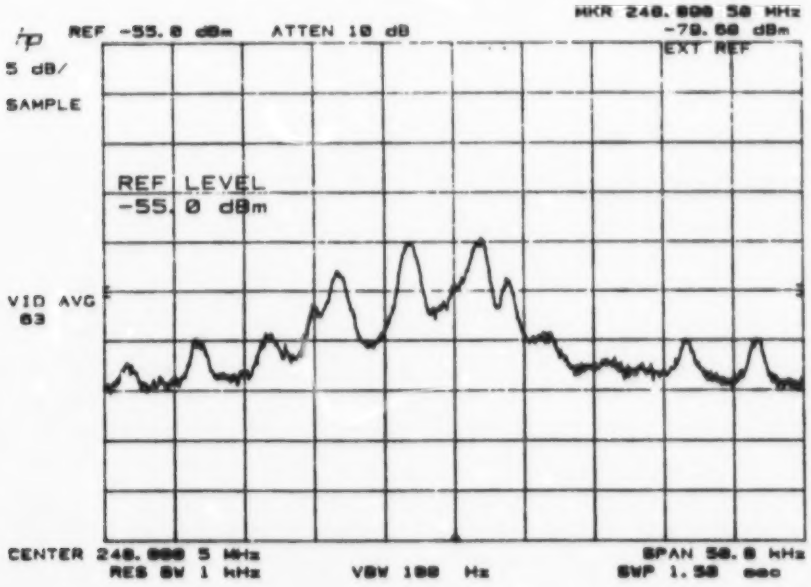

Fig. 4.2. Spectral density of subchannel 3.

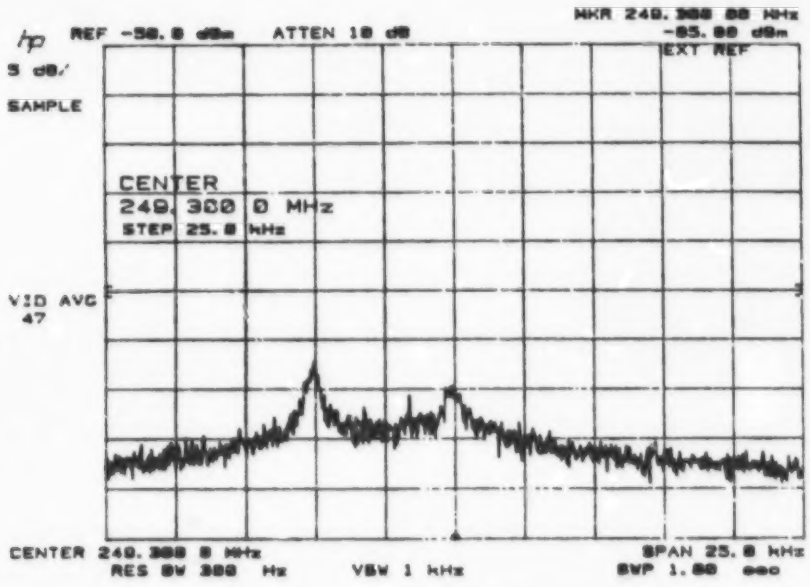

Fig. 4.3. Spectral density of subchannel 19.

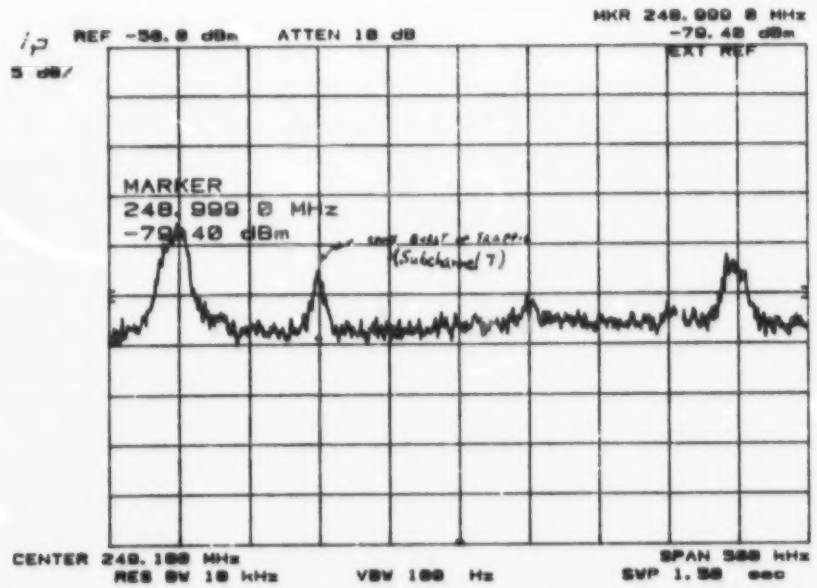

Fig. 4.4. Spectral density of wideband channel with burst traffic.

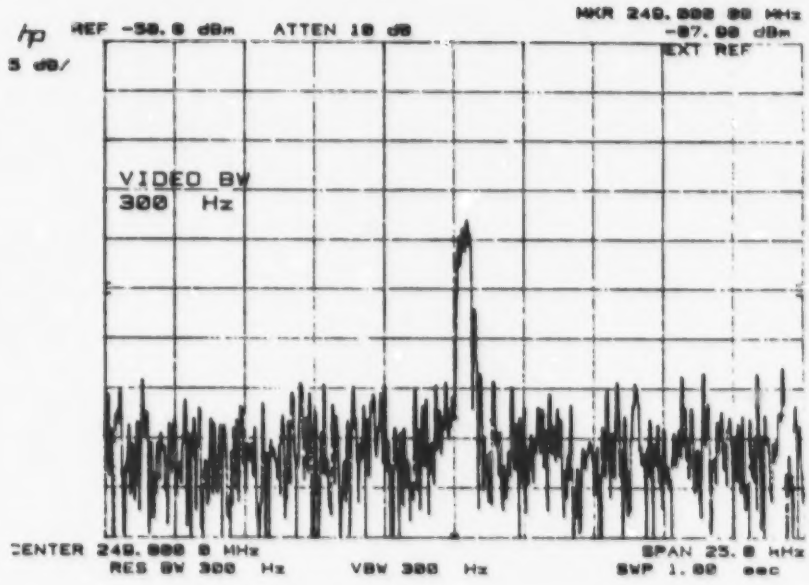

Fig. 4.5. Spectral density of subchannel 7.

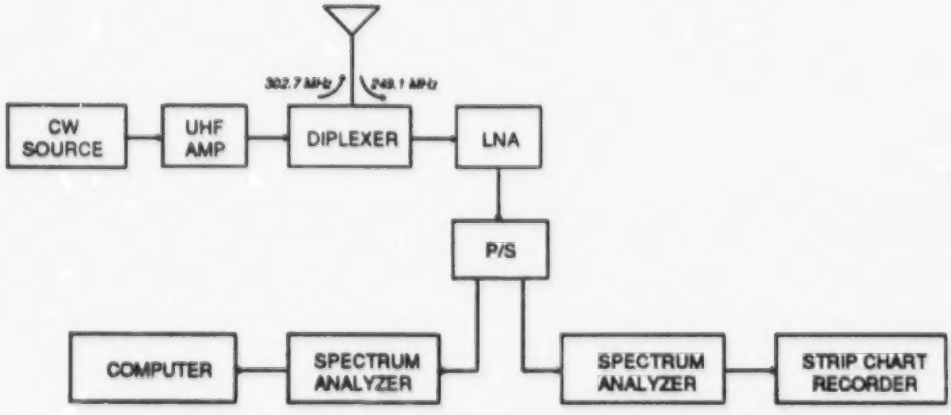

Fig. 4.6. Experimental set up to measure C/N_o over the MARISAT wideband channel.

Link calculations similar to those provided in Section 3.2 are given below to derive the expected terminal C/N_o. This value provides only a rough estimate of the terminal C/N_o since the path loss, terminal antenna gain, transponder loading, and hence, SNR suppression factor, are not measured quantities. Based on the observed spectral density of the transponder downlink, the assumed transponder loading consists of only two signals: the CW signal and the interference in subchannel 3. Furthermore, the downlink SNR of the subchannel 3 signal was observed to be approximately 4.2 dB above the downlink CW signal. Where appropriate, the equation numbers from Section 3.1 are included next to the calculation.

UHF transmit power	11.5 dBW
Cable, diplexer losses	2.2 dB
Antenna gain	10 dBi
Terminal EIRP	19.3 dB
Uplink path loss	173.9 dB
Satellite Receive Antenna Gain	10.5 dBi
Transponder Received Signal Power (3-1)	-144.1 dBW
Transponder system noise PSD	-200.1 dBW/Hz
Transponder bandwidth	500 kHz
System Noise Power	-143.1 dBW
Transponder input SNR (3-2)	-1.0 dB
SNR suppression factor (approximate)	-4 dB
Transponder output SNR (3-3)	-5.0 dB
Transponder EIRP	28.0 dBW
Downlink path loss	172.4 dB
Terminal receive antenna gain	10.0 dB
Terminal total received power (3-4)	-134.4 dBW
(Total received power = CW signal + subchannel 3 signal)	
Signal power (for CW signal) (3-5)	-142.7 dBW
Terminal received noise power (3-6)	-139.4 dBW
Terminal system noise PSD	-200.0 dBW/Hz
Effective receiver noise PSD (3-7)	-194.9 dBW/Hz
C/N_o (3-8)	52.2 dB·Hz

The measured terminal C/N_o over a 24-hour period is illustrated in Fig. 4.7. Each data point in Fig. 4.7 is obtained by measuring the carrier power and noise PSD once a minute and then averaging these values over six minutes. The mean C/N_o is approximately 44.5 dB·Hz with an rms variation of approximately 3 dB. For comparative purposes, the received carrier power and noise PSD are separately plotted in Fig. 4.8 and Fig. 4.9, respectively.

The plot of received carrier power in Fig. 4.8 shows two rapid decreases (greater than 5 dB) at around the 8 and 16 hour marks. These periods are both approximately 3 hours in duration. With only a single, relatively low EIRP CW signal transmitted, the transponder is lightly loaded. It would be therefore be very sensitive to other higher power users/sources. It is quite likely that the intermittent users are the cause of the dramatic variations in carrier power and, as a result, the measured terminal C/N_o.

The effective noise spectral density at the terminal, plotted in Fig. 4.9, is also observed to decrease at around the 8 and 16 hour marks. This is consistent with the theory of additional high power sources at these times. Changes in the transponder loading will cause changes in the transponder output noise power and intermodulation products. These changes will in turn be observed at the terminal as fluctuations in the noise PSD. The noise PSD at the terminal, which is dominated by the downlink noise, is expected to decrease in magnitude as additional users are added to the system. The carrier power will decrease by a greater amount, however, and thus leads to a decrease in C/N_o. By excluding the N_o values at around the 8 and 16 hour marks, the peak N_o variation is observed to be approximately 5 dB.

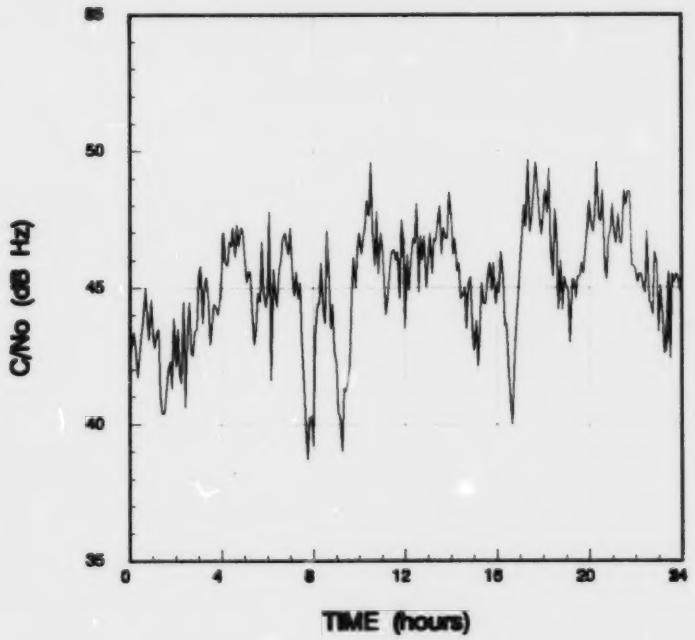

Fig. 4.7. Measured terminal C/N_o over a 24-hour period.

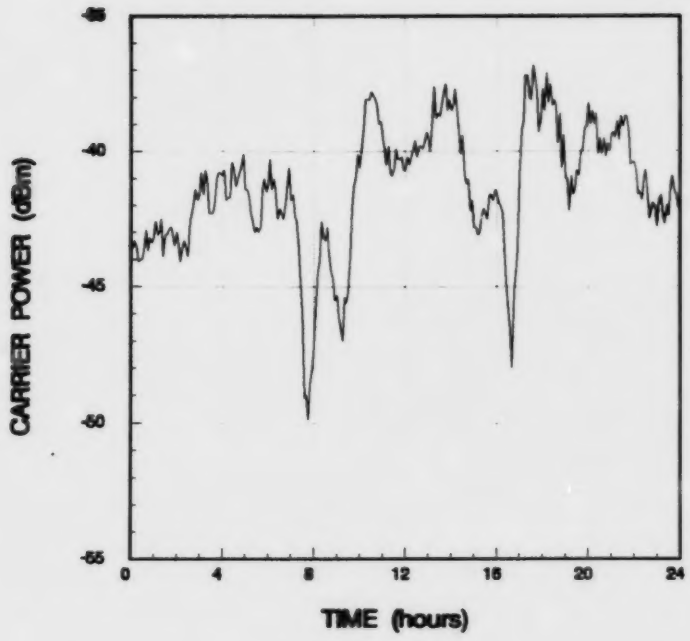

Fig. 4.8. Measured terminal receive carrier power over a 24-hour period.

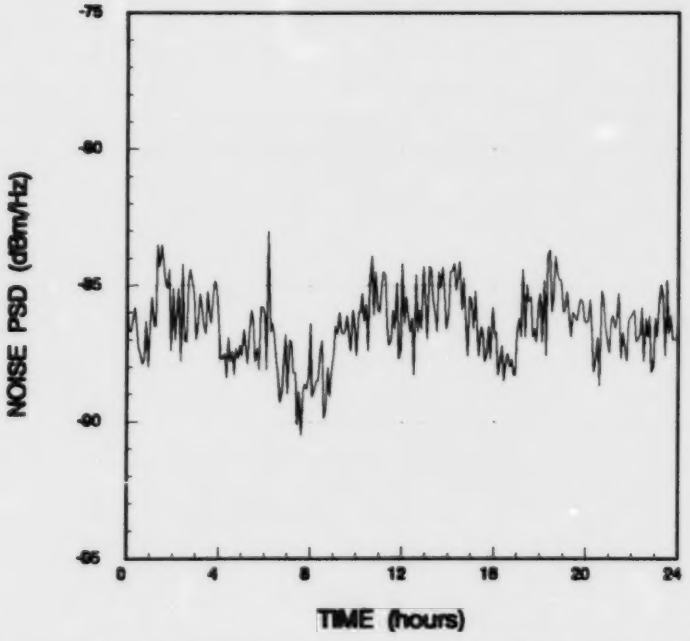

Fig. 4.9. Measured terminal noise PSD over a 24-hour period.

The strip chart recording of the carrier power is in agreement with the carrier power recording shown in Fig. 4.8. Since the chart was running continuously, it is easier to observe burst traffic. On a number of occasions the carrier power was observed to instantaneously decrease by just over 1 dB for approximately 1 minute, and then return just as quickly to the same nominal value. This decrease in carrier power is largely attributed to the increase in the user SNR suppression factor. In general, the carrier power was observed to vary by less than 1 dB over most 1 minute intervals and often over many tens of minutes.

4.3 DISCUSSION OF MEASUREMENTS

The spectrum usage measurements show the transponder to have a relatively high level source in subchannel 3 and a moderate level source in subchannel 19. The C/N_o measurements demonstrate the sensitivity of a low EIRP user using a lightly loaded hardlimiting transponder. This observation also underlines the vulnerability in using UHF non-processing transponders. The wide coverage antennas used in this band provide easy access for authorized as well as unauthorized users or interfering signals. The variation in C/N_o and individual carrier and noise PSD components were considerable over the 24-hour period, thereby justifying the use of at least a 3 dB link margin. Any changes in path loss and antenna gain over this period are difficult to assess due to the arrival and departure of other signals.

5 CONCLUSIONS

An analysis has been performed on the feasibility of using the MARISAT satellite UHF wideband channel for user data rates of 2.4, 4.8 and 16 kbps. A variety of transponder loading schemes were analyzed. A general conclusion from the analysis is that the transponder offers very little capacity (at most 4 users) for data rates of 16 kbps. There is however plenty of capacity (well over half of the twenty subchannels) for users transmitting at 2.4 or 4.8 kbps.

A preliminary evaluation of the wideband channel spectrum usage showed at least two constant sources with one source considerably larger than the other. C/N_o measurements over a 24-hour period demonstrated the susceptibility of C/N_o fluctuations due to other user burst traffic when communicating over an otherwise lightly loaded hardlimiting transponder. The C/N_o monitoring also revealed that a 3 dB link margin is sufficient when the transmission burst duration is of the order of a few minutes.

6 ACKNOWLEDGEMENTS

The SNR suppression factor calculations were performed by Dr. T. Aaron Gulliver. The experiments were set up and run by Mr. Ray Burrill and Mr. Al McEwen. Their contributions are appreciated.

7 REFERENCES

[1] B. F. McGuffin, Loading the LES-9 Wideband UHF Transponder, Lincoln Laboratory Technical Report 882, 21 June 1990.

[2] Navy UHF Satellite Communication System Description, prepared by Naval Ocean Systems Center, San Diego, California, 1 July 1980.

APPENDIX A - SNR SUPPRESSION FACTOR

The user SNR suppression factor is given in Tables A.1-7 for the transponder loading cases given in Table 3.2.

Number of Users L	SNR Suppression Factor (dB)
2	-1.8
3	-2.4
4	-3.1
5	-3.7
6	-4.1
7	-4.6
8	-4.9
9	-5.3
10	-5.6

Table A.1. SNR suppression factor for L terminals at EIRP=20 dBW.

Number of Users L	SNR Suppression Factor (dB)
2	-4.1
3	-4.7
4	-6.0
5	-6.8
6	-7.4
7	-8.0
8	-8.6
9	-9.0
10	-9.5

Table A.2. SNR suppression factor for L terminals at EIRP=25 dBW.

Number of Users L	SNR Suppression Factor (dB)
2	-7.2
3	-8.4
4	-10.1
5	-10.9
6	-11.7
7	-12.4
8	-13.0
9	-13.6
10	-14.0

Table A.3. SNR suppression factor for L terminals at EIRP=30 dBW.

Number of Users L	SNR Suppression Factor (dB)	
	L-1 users at 20 dBW	1 User at 17 dBW
2	-1.0	-1.8
3	-2.1	-2.4
4	-2.8	-3.1
5	-3.4	-3.6
6	-3.9	-4.1
7	-4.3	-4.5
8	-4.7	-4.9
9	-5.1	-5.2
10	-5.4	-5.5

Table A.4. SNR suppression factor for L-1 Users at EIRP=20 dBW, 1 User at 17 dBW.

Number of Users L	SNR Suppression Factor (dB)	
	L-1 users at 20 dBW	1 User at 23 dBW
2	-2.8	-1.4
3	-3.1	-2.4
4	-3.7	-3.1
5	-4.1	-3.7
6	-4.5	-4.2
7	-4.9	-4.6
8	-5.3	-5.0
9	-5.6	-5.4
10	-5.9	-5.7

Table A.5. SNR suppression factor for L-1 Users at EIRP=20 dBW, 1 User at 23 dBW.

Number of Users L	SNR Suppression Factor (dB)	
	L-1 users at 22 dBW	1 User at 25 dBW
2	-3.8	-2.0
3	-4.1	-3.3
4	-4.7	-4.1
5	-5.3	-4.8
6	-5.8	-5.4
7	-6.2	-5.9
8	-6.6	-6.4
9	-7.0	-6.7
10	-7.3	-7.1

Table A.6. SNR suppression factor for L-1 Users at EIRP=22 dBW, 1 User at 25 dBW.

Number of Users L	SNR Suppression Factor (dB)	
	L-1 users at 25 dBW	1 User at 22 dBW
2	-2.0	-3.8
3	-4.3	-4.7
4	-5.4	-5.9
5	-6.4	-6.6
6	-7.1	-7.3
7	-7.8	-7.9
8	-8.3	-8.5
9	-8.8	-8.9
10	-9.2	-9.4

Table A.7. SNR suppression factor for L-1 Users at EIRP=25 dBW, 1 User at 22 dBW.

APPENDIX B - C/N_o CALCULATIONS

The user C/N_o calculated for the loading schemes given in Table 3.2 are listed below in Tables B.1-7.

Number of Users L	C/N_o per user (dB Hz)
2	53.8
3	52.9
4	52.2
5	51.5
6	51.0
7	50.5
8	50.1
9	49.7
10	49.4

Table B.1. Terminal C/N_o for terminal EIRP=20 dBW.

Number of Users L	C/N_o per user (dB Hz)
2	56.0
3	55.1
4	53.8
5	53.0
6	52.3
7	51.7
8	51.1
9	50.7
10	50.2

Table B.2. Terminal C/N_o for terminal EIRP=25 dBW.

Number of Users L	C/N_o per user (dB Hz)
2	57.4
3	56.0
4	54.4
5	53.6
6	52.8
7	52.1
8	51.5
9	50.9
10	50.5

Table B.3. Terminal C/N_o for terminal EIRP=30 dBW.

Number of Users L	C/N_o per user (dB Hz)	
	L-1 users at 20 dBW	1 User at 17 dBW
2	54.7	50.8
3	53.4	50.0
4	52.5	49.2
5	51.8	48.6
6	51.3	48.1
7	50.7	47.6
8	50.3	47.1
9	49.9	46.8
10	49.6	46.5

Table B.4. Terminal C/N_o for L-1 users at EIRP=20 dBW and 1 user at EIRP=17 dBW.

Number of Users L	C/N_o per user (dB Hz)	
	L-1 users at 20 dBW	1 User at 23 dBW
2	52.5	56.9
3	52.1	55.8
4	51.4	55.0
5	51.0	54.4
6	50.5	53.8
7	50.1	53.4
8	49.7	53.0
9	49.3	52.5
10	49.0	52.2

Table B.5. Terminal C/N_o for L-1 users at EIRP=20 dBW and 1 user at EIRP=23 dBW.

Number of Users L	C/N_o per user (dB Hz)	
	L-1 users at 22 dBW	1 User at 25 dBW
2	53.2	58.0
3	52.9	56.7
4	52.2	55.8
5	51.6	55.1
6	51.1	54.5
7	50.6	53.9
8	50.2	53.4
9	49.8	53.1
10	49.5	52.7

Table B.6. Terminal C/N_o for L-1 users at EIRP=22 dBW and 1 user at EIRP=25 dBW.

Number of Users L	C/N_o per user (dB Hz)	
	L-1 users at 25 dBW	1 User at 22 dBW
2	58.0	53.2
3	55.6	52.2
4	54.4	50.9
5	53.4	50.2
6	52.6	49.4
7	51.9	48.8
8	51.4	48.2
9	50.9	47.8
10	50.5	47.3

Table B.7. Terminal C/N_o for L-1 users at EIRP=25 dBW and 1 user at EIRP=22 dBW.

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The use of the **MARISAT** satellite **UHF** wideband channel as a radio link for multiple users is investigated. An analytical evaluation of the link is performed for up to 10 users sharing the non-processing transponder's 500 kHz bandwidth. The terminal link carrier-power-to-noise-power-spectral-density ration, C/N_o, is evaluated for data rates of 2.4, 4.8 and 16 kbps and for terminal effective isotropic radiation power (EIRP) levels from 17 to 30 dBW. Analyses are performed for cases in which all terminals transmit with the same EIRP and also fro cases in which a single user is either 3 dB above or below the other users. A variety of loading schemes are considered to demonstrate the variation in user SNR degradation due to hardlimiting on-board the transponder. The terminal C/N_o is compared to the minimum performance requirement plus a 3 dB margin to determine the link capacity.

Two experiments which were run to evaluate the **MARISAT UHF** wideband channel spectrum usage and to measure the terminal C/N_o are described. Power spectral density graphs of the wideband channel and individual subchannels are presented. The results of a 24-hour test to monitor the terminal C/N_o is discussed in terms of the observed C/N_o fluctuations and spectrum anomalies.

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